16 Years of Experience with Rule Based Control of Copenhagen's Sewer System

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16 Years of Experience with Rule Based Control of Copenhagen's Sewer System

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Abstract: The sewer system in Copenhagen started implementing Real Time Control (RTC) in the 1990's in a small subcatchment. The method used was and still is rule based control. Since then the use of RTC has been expanded to the whole catchment and continuously improved from operational experience. These experiences are shared and put into a framework to be used for a common understanding of the problems that can be solved using rule based control and control in general. Benefits and limitations of using rule based control are examined and future perspectives of the control structure of Copenhagen are outlined.

Keywords: Real Time Control; Rule based control; Operational experience

1. INTRODUCTION

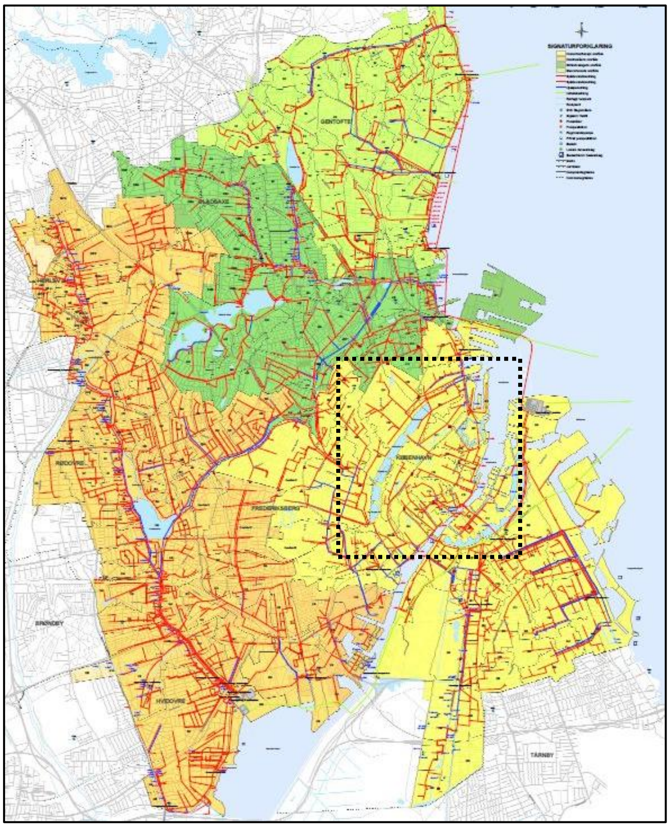
The sewer system in Copenhagen is more than 150 years old. In the beginning the wastewater was not treated but simply transported away from the city centre and discharged into the harbour. Figure 1 shows the sewer system in Copenhagen in 1876.

Since then the city as well as the sewer system has expanded considerably as it can be seen from Figure 2.

Today the sewer system has many actuators and measurements, to ensure a good surveillance, regulation and operation. The vision for the future is an integrated control with the wastewater treatment plants to ensure a better operation of both systems.

Real Time Control (RTC) of the Copenhagen sewer system was first implemented in the 1990's. The Wastewater Utility operating the sewer system in Copenhagen decided to implement RTC in the western part of the system.

Figure 1: Map showing the sewer system in Copenhagen in 1876.



The goal of using control was to ensure a better utilization of some large pipe volumes in the catchment. The implementation proved successful and since then the Wastewater Utility of Copenhagen has continued to implement control in other parts of the system.

Much can be learned from the operational experienced gained from the last 16 years of operating the sewer system with controls; how the controls where originally developed, how they have evolved and how the system is controlled today. The experiences with RTC are therefore described in the following sections.

Figure 2: The wastewater system in Copenhagen (and surrounding municipalities). The box indicates the size of the city in 1876 (see Figure 1).

2. THE DEVELOPMENT OF THE CONTROL SYSTEM FOR THE SEWER SYSTEM

As mentioned earlier the sewer system today is controlled to optimize the operation of the system. Originally the sewer system only had local controls (on/off). The actuators were merely there to lift the water, as the water mainly runs by gravitation towards the wastewater treatment plants. However, around the 1990's the Wastewater Utility operating the sewer system in Copenhagen decided to implement some more advanced RTC in the western part of the system. The goal of using RTC was to ensure a better utilization of some large pipe volumes in the catchment.

2.2 The design of the first RTCs in 1990's

In the 1990's large pipes were identified as not being effectively utilized. During rain events they would be less than half full while the system would overflow at the downstream CSOs. Gates where installed that made it possible to store water is the pipes during rain. The basis of the control was rule based switching between dry weather, wet weather and emptying operation of the system (PH-Consult, 1990).

By introducing the rule based control the primary objective of the use of the basin could be changed according to the state of the system. During dry weather the gates are open, because the primary function of the pipes are to transport any seepage to the wastewater treatment plant. But as soon as the measurements indicate that it is raining enough to cause a hydraulic overload downstream, the gates are closed, so the pipes can act as retention basins. Once it stops raining and there starts to be free capacity downstream, the sequence goes to the emptying phase, where the gates open in a controlled way to ensure that the downstream areas are not flooded due to too fast release of the retained water. By defining these three states, the operation of the system could run in a sequence.

The control system for the individual gates can be illustrated as it is done in Figure 3.

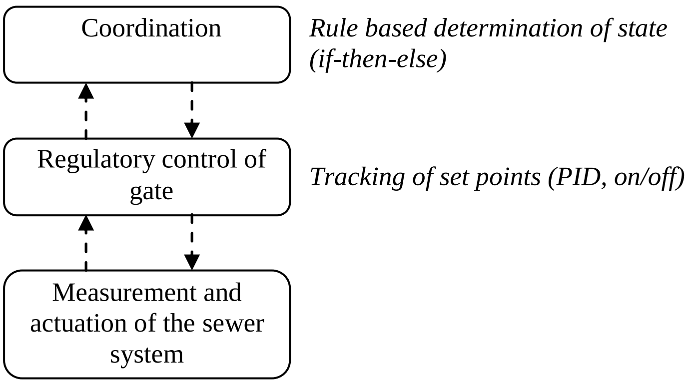


Figure 3: Control structure for gate with rule based control (based on Skogestad, 2002)

By installing gates and adding rule based control, the CSO was reduced by 80 % and the emptying time reduced from 40 to 2-3 hours (Andersen et al., 1997).

2.2 The evolution of RTC in Copenhagen

Over the years the amounts of rainfall runoff the sewer system is expected to handle has increased and the distribution of it has changed. Also regulation has changed, setting strict limitations on allowed annual number of CSOs. To keep with the regulation and the service level of the system with respect to the frequency of flooding and numbers of CSOs, retention basins have been built across the catchment. With the increasing number of basins and pumping stations, the need to coordinate the actuators became apparent. For example if two basins are being emptied towards the same downstream pipe that has a limited capacity, the emptying of the basins need to be coordinated to ensure that the capacity of the downstream pipe is not exceeded. In practice one of the basins is usually given first priority and the coordination is implemented as a supervisory control imposing a constraint on the maximum output of the actuator with the lowest priority. This is visualized in Figure 4. The prioritisation can be based on for example the differences in storage or the sensitivity of the receiving water body.

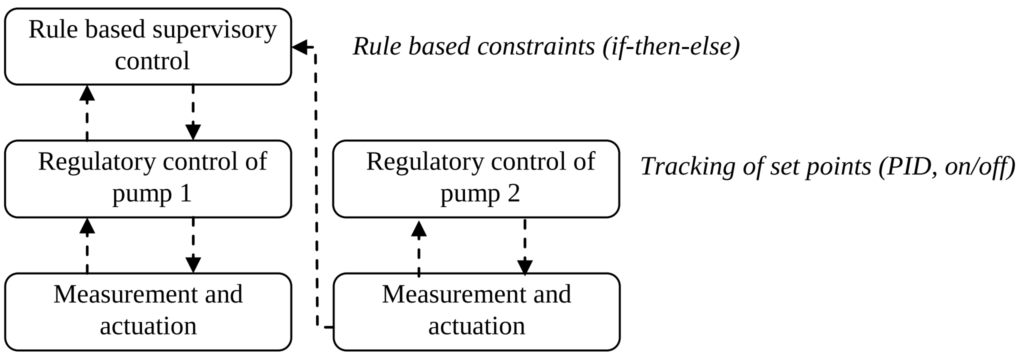


Figure 4: Example of possible control structure for two pumps that are pumping towards the same bottleneck.

The advantage of using rule based control is that it is an intuitive way of controlling ones system. However, with respect to coordinating the actuators, the rule based control has the limitation that it is a fixed prioritisation between the actuators involved. Since rainfall is rarely evenly distributed over the catchment, this type of control will not always function with the same effectiveness, due to changing distribution of loads on the actuators of the system.

Today the sewer system of Copenhagen has many actuators (a total of 80 pumping stations and gates) and even more sensors. That however does not mean that all actuators have more advanced controls than on/off. The controls are still based on the local state of the system and therefore rule based control is only interesting if one of two criteria exist:

1. There is a need for supervisory control: A downstream bottleneck exists and by constraining the manipulated variables (actuators) the operation of the system will improve. E.g. flooding is minimized or combined sewer overflow (CSO) is reduced.
2. There is a need for optimization: There are several different objectives of the actuator e.g. maximise transport of water to treatment, minimize CSO (by storing water), minimise electricity consumption.

Due to the possibility of using rule based control, large pipe basins have become an often preferred solution, due to the ability to both store and transport water. Another benefit of the rule based control is the reduction in emptying time of the basins. By coordinating the emptying of the different basins, the time it takes can be kept at a minimum. Finally energy optimised operation of pumps during dry weather has resulted in a saving in the energy consumption. At stations with energy optimised operation, the energy consumption during dry weather is reduced by 15 %.

2.2 The vision for RTC in Copenhagen

The vision for the Wastewater Utility in Copenhagen is to have a more integrated operation between the sewer system and the wastewater treatment plant (WWTP). However, this would mean that the key bottleneck would become the inlet to the WWTP and all upstream actuators would have to be coordinated according to this. Keeping with the existing strategy where the control of the sewer system is distributed to the local PLCs at all levels of the hierarchy seems like a too complex problem to be solved with rule based control. Therefore the Wastewater Utility of Copenhagen is looking at new methods of coordinating the actuators; Methods with a more dynamic prioritisation between the actuators.

3. CONCLUSION

Since the first rule based control was implemented in the western part of Copenhagen in 1996, the principles have been extended to the rest of the system as well as improved from operational experiences.

There are many benefits of using rule based control, the primary being it is very intuitive way of controlling the sewer system. However, as the ambitions with RTC grow, the applicability of rule based control may reach its limitation.

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